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WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

2470

Reference No. 53-94

A MANUAL FOR FREE DIVERS, With Especial Reference to the Aqua-Lung

by D. M. Owen

2470

Interim Report No. 1
Submitted to Geophysics Branch, Office of Naval Research
Under Contract Nonr-769(00)(NR-083-069)

December 1953

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ACKNOWLEDGMENTS

In the preparation of this report, the author has enjoyed the assistance of others with wider experience.

Generally speaking there is not complete accord--in this early stage of the art--on all aspects of underwater swimming; the author has considered various points of view in arriving at the conclusions offered in this report. The objectives required in military operations often conflict with, or modify, the civilian method. However, the reader should realize that concerning "survival in the water" the difference of opinion is very small.

The author is particularly indebted to the following individuals, all experts in various phases of self-contained diving, for helpful criticism of the original manuscript.

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INTRODUCTION

Anticipating the increasing use of underwater swimming and diving techniques at the Woods Hole Oceanographic Institution, particularly with the Cousteau Aqua-Lung apparatus, the author has assembled a number of facts and opinions. These are gathered from his own and colleagues' experiences, from scattered references, and from the personal advice of U. S. Navy personnel, for the purpose of familiarizing the beginning diver with many of the factors involved in a successful dive.

<u>This manual is not intended to substitute for the personal supervision of experienced and competent underwater swimmers.</u>

The ease with which most self-contained underwater breathing apparatus can be used may invite the student diver to enter the water ignorant of potential dangers and ways of avoiding them. Even the experienced diver may be confronted by dangers stemming from the environment or from possible carelessness.

For more details concerning Aqua-Lung maintenance, physiological aspects of diving, and the mechanics of undersea exploration, the reader should refer to the bibliography; references in the text are indicated by underlined numbers in parenthesis.

Although this report is not intended to be a complete guide for all phases of self-contained diving, dwelling instead on many problems which affect the efficiency and safety of the Aqua-Lung diver in particular, the greater percentage of the material presented will apply equally as well to many other means of self-contained diving which use air for breathing.

Self-contained diving is a relatively new activity, continually increasing in scope, and surprisingly little has been done to collect detailed information and reference material under one cover.

This report should also answer many questions from interested parties--diving students, fellow workers, project supervisors, etc.--which cannot be found answered in the available literature. The diver of some experience may also be interested.

Discussions of cold-water swimming, underwater communication, the use of the less common semi-closed or closed circuit apparatus (oxygen re-breather type), the advantages or disadvantages of using such apparatus in place of the Aqua-Lung, use of gas mixtures other than air, and hazards facing the diver from marine life are beyond the scope and intent of the present manual. Concerning the latter the reader may draw his own conclusions, assisted by the reference material provided. From his limited experience with cold-water swimming, the author believes that the adverse effects of such

activity deserve the utmost consideration from the efficiency and safety viewpoints.

Finally, it was not the author's intention to discuss the more pleasant aspects of free diving. To allay the reader's possible doubts, it must be stressed that Aqua-Lung diving is not one steady procession of difficulties and potential hazards, but can be a very enjoyable and rewarding experience to the oceanographer who has an understanding of many problems which accompany the great privilege of direct observation.

APPENDIX

As this report goes to press, the author wishes to call attention to some more recent contributions which illustrate the expanding use of self-contained diving apparatus among oceanographers.

1. The reader will observe in Section I that the author "assumes that the prospective Aqua-Lung diver is already a proficient swimmer, etc." This statement should be strengthened. Lack of ability to swim well can only lead to trouble, at least in the long run; the reader is urged to consider the recommendations of a diver of long experience. See Qualifications for a diving certificate and An outline of diving regulations, by Conrad Limbaugh, of the University of California, Scripps Institution of Oceanography. The former, especially, will suggest some swimming exercises appropriate as training prior to Aqua-Lung instruction.

The "Outline of recommended training for Woods Hole Oceanographic Institution diving candidates" found in Section IV should also be read with this discussion in mind.

2. The following two references, in addition to reference no. 22 in the Bibliography, will be valuable to the reader interested in some underwater techniques used with obvious success in a submarine geological survey:

(a) Underwater Mapping by Diving Geologists, by H. W. Menard, R. F. Dill, E. L. Hamilton, D. G. Moore, G. Shumway, M. Silverman, and H. B. Stewart. Bull. Amer. Assoc. Petrol. Geol., Vol. 38, No. 1, pp. 129-147

(b) Geologic Use of Self-Contained Diving Apparatus, by R. F. Dill and G. Shumway. Bull. Amer. Assoc. Petrol. Geol., Vol 38, No. 1, pp. 148-157, January 1954

SECTION I - Mechanics of the Dive

This section assumes that the prospective Aqua-Lung diver is already a proficient swimmer, with considerable experience in using the mask and swim fins. Surface diving occasionally to depths of perhaps 30 feet is excellent preparation. It has been found that the individual having little or no previous experience with face mask or swim fins has some difficulty in adapting to the Aqua-Lung.

The ideal location for the initial dive is a swimming pool or gently sloping beach. Later, following an anchor line to the bottom will often increase confidence in the beginner during his first descent to any considerable depth.

The Aqua-Lung is actually quite easy to use but training involving a number of weeks or months usually is necessary before the student really can be considered proficient and capable of making concentrated observations of his surroundings. In the majority of cases during the initial dives, the student is mainly preoccupied with "keeping alive" in the new medium.

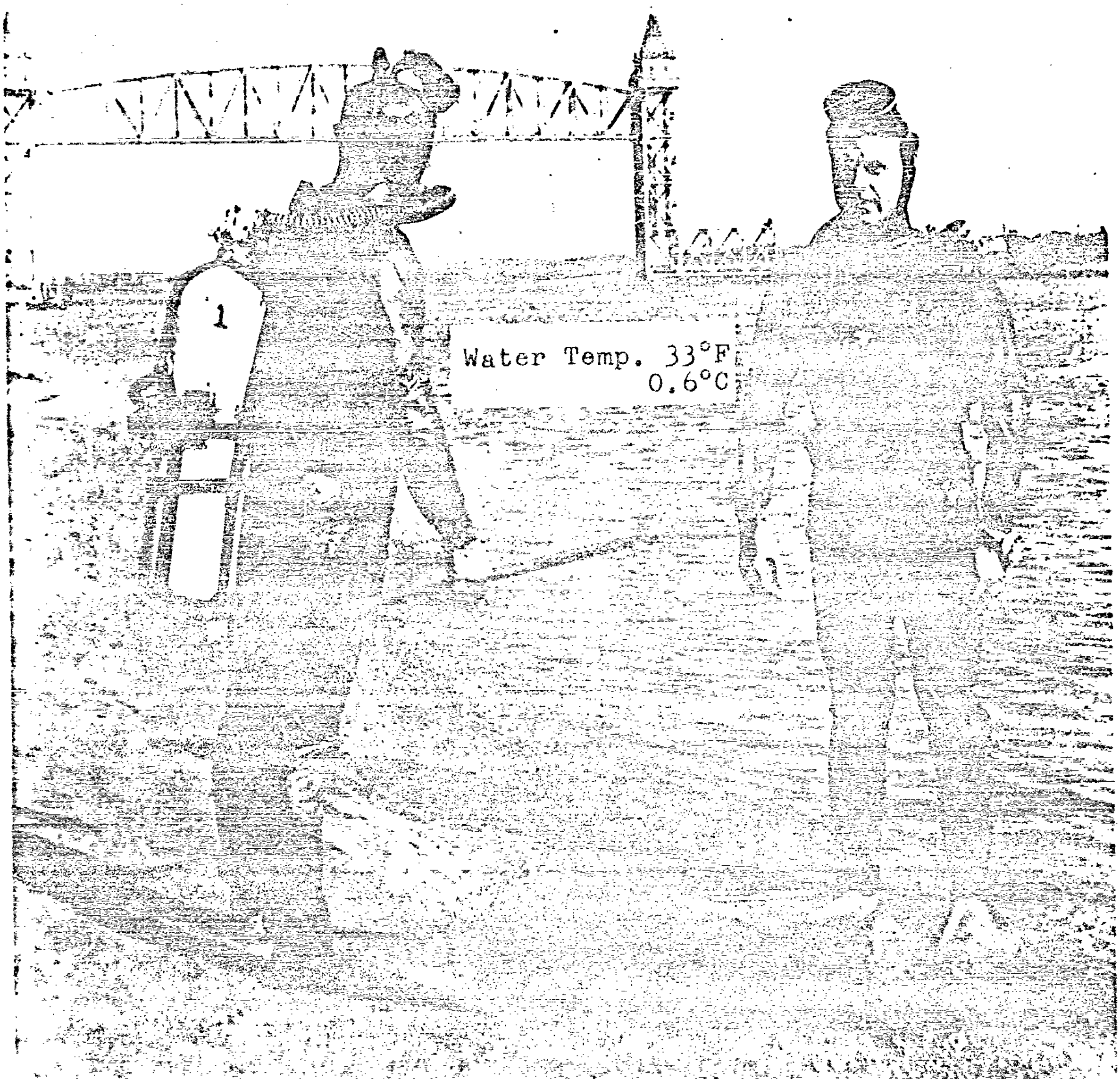
A. Equipment Check

To prevent the face mask from fogging, smear saliva around inside the face plate and follow with a quick rinse in the water. Saliva is one of the best anti-fog substances.

Check tightness of mask seal by attempting to inhale through the nose. If watertight a suction will result, drawing the glass towards the nose. It has been the author's experience that a mustache or beard may have to be sacrificed to attain this tightness.

Inspect the rubber flapper exhaust valve, in the regulator box assembly, to insure that the slits are not stuck together. The valve must open completely when exhaling and close completely when inhaling. If the valve does not close completely, water will enter the breathing tubes. This may be caused by salt particles if the valve was not properly rinsed in fresh water after the previous dive. The valve may also show signs of deterioration, usually requiring replacement about once a year.

The cylinder pressure, which should never exceed the maximum rated pressure, must be checked before entering the water and a rough estimate of the diving time may be obtained from the graph illustrating duration of air supply at various depths (Fig. 3) It must be remembered that the beginning diver will most likely consume at least twice as much air as the experienced diver who has learned to control his breathing.



The Aqua-Lung at Cape Cod Canal, Massachusetts

February 1953

FIG. 1

After the demand regulator has been clamped to the air cylinder and before turning on air, the hoses must be tested for leaks by drawing on the mouthpiece. The hoses must also be examined for signs of deterioration, or cracks, or looseness where attached to the regulator.

Turn on the air and breathe several times through the mouthpiece to test the action. If operating properly a very slight resistance will be felt on inhaling, but the diver soon accustoms himself to this peculiarity. The regulator will furnish sufficient air with normal demand.

Then place the mouthpiece to the ear. A continuous slight hissing sound at this point indicates that the regulator needs an internal adjustment or overhaul (*). This leak is an abnormal condition and should be remedied before attempting a deep dive.

B. <u>Buoyancy Determination</u>

Buoyancy adjustment depends on the individual body build and desires. For an effortless descent and ascent the diver should be somewhat negatively buoyant with a full tank and slightly positive with an exhausted tank. If much stationary work on the bottom is required, the Aqua-Lung diver may prefer to be negative at all times. In fact, some individuals have inherent negative buoyancy even without carrying diving apparatus.

For most underwater activities, however, the diver will prefer approximately neutral buoyancy and the follow ng procedure is recommended:

With the Aqua-Lung cylinder about 50% exhausted (approx. 1100 p.s.i.) slip off a float into water 8 or 9 feet deep. While standing vertically in the water, with the arms at the sides and legs motionless, exhale completely. If neutral you will sink slowly to the bottom, only to begin rising as a full breath is taken. If this is not the case add weights, one pound at a time, until this control is achieved.

Adjustment to neutral buoyancy will enable a diver to make small depth corrections simply by breathing control, and results in the most effortless dive. Otherwise, much air is wasted by constant maneuvering to maintain the desired depth level.

(*) Consult <u>Overhauling the Aqua-Lung</u>, Scripps Institution of oceanography Reference #53-28, April 1953.

While on the subject of weights it might be interesting to note that a 70 cubic foot Aqua-Lung cylinder charged to 1800 p.s.i., with regulator attached, will weigh about 36 pounds in air and 2.1 pounds in sea water. The same tank when exhausted may have a slight positive buoyancy of about 4 ounces.

In determining or adjusting his buoyancy with the apparatus, the diver should make allowances for the accessories likely to be carried. A cold-water exposure suit will also affect the ballast weight requirements because of its trapped air pockets and different volume. As an example, the author requires an additional 3 pounds ballast for neutral buoyancy with the 70 cubic foot tank and wearing bathing trunks, while a certain type of full-length rubber suit with hood requires a total of 14 pounds for the same buoyancy. When using the 70 cubic foot tank with bathing trunks in <u>fresh</u> water, the author is very slightly negative--without <u>any</u> ballast.

The author observed on one occasion that although his buoyancy was neutral near the surface (without a rubber suit), he became slightly negative at a depth of 100 feet. Near the bottom at this depth a full inhalation only enabled him to maintain his present level, while a complete exhalation caused him to drop quite rapidly. Although this phenomenon caused no inconvenience, the experience may be interesting in that the very slight compression of tissues under the pressure of 4 atmospheres was enough to slightly reduce the buoyancy.

C. Swimming Form and Descent

When covering any distance under water with the Aqua-Lung the best swimming form consists of keeping the arms at the sides (*) and kicking the legs in slow sweeps. The knees should be slightly bent; excessive bending is inefficient. Using the arms will actually impede the diver. With the recommended swimming form, a minimum consumption of air is possible and maximum speed may be obtained. The average swimming speed with the Aqua-Lung, when used by a proficient diver, is about 0.9 knots.

For the most rapid descent a vertical head-first position may be assumed. "Clearing" the ears, however, will

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(*) Exception: when visibility is poor, arms may be extended in front, so any object encountered will first be contacted with the hands--not the head. The same form should be used on ascent to the surface, regardless of the visibility, to protect the head from the hull of a boat, etc.

govern the speed of descent. With conditioning of the eustachian tubes and experience it is possible to swim down the first 100 feet within one or two minutes.

The ears may soon experience a "wedging" sensation, sometimes within 10 or 15 feet below the surface. In cases of unusual blockage, this may be experienced within 6 to 10 feet below the surface. If discomfort in the ears persists or worsens, stop completely for a few seconds and allow the air pressure to equalize fully in the passages. To facilitate the process the diver may blow through the nose while holding the mask firmly against the face, wiggling the jaws, or swallowing. Temporarily ascending a few feet often helps in the failure to equalize.

Navy U.D.T. swimmers find that a nose clip (*) worn under the mask will assist in clearing the ears more effectively than the foregoing procedures, if a slight pressure is blown against the clip during descent. This clip will not interfere with the normal equalization of the mask air space pressure, nor with the elimination of water leakage from the mask (see Sect. III-A).

If the discomfort cannot be eliminated return to the surface or settle for a shallower depth. Otherwise there is a strong possibility of eardrum rupture or a hemorrhage from the middle ear and tympanic membrane through the eustachian tubes (see Sect. V).

The attempts to equalize should not be pushed to the point of distinct pain since considerable damage to the delicate tissues can occur without extreme discomfort. If ear discomfort persists on repeated diving sessions, despite the foregoing measures, the prospective diver should be examined by an ear-nose-throat specialist.

Under the ideal training program the trainee should be examined before the initial dive and treated, if necessary, where the student with potential equalization difficulties wishes to continue in the diving program. In the case of excess lymphatic tissue around the eustachian tube opening it may be necessary to enlarge the entrance through a series of radium treatments.

Never dive with ear plugs. They trap air inside the ears which reacts to pressure changes. Water pressure can force the plugs deep into the ears. The same rule should apply to the use of goggles, unless there is some means of equalizing the pressure.

(*) The DESCO nose clip appears to be suitable.

A more detailed discussion of routine ear care and complications following eardrum rupture, "ear squeeze", and "mask squeeze" will be found in Section V.

D. Breathing Control and Conservation of Air

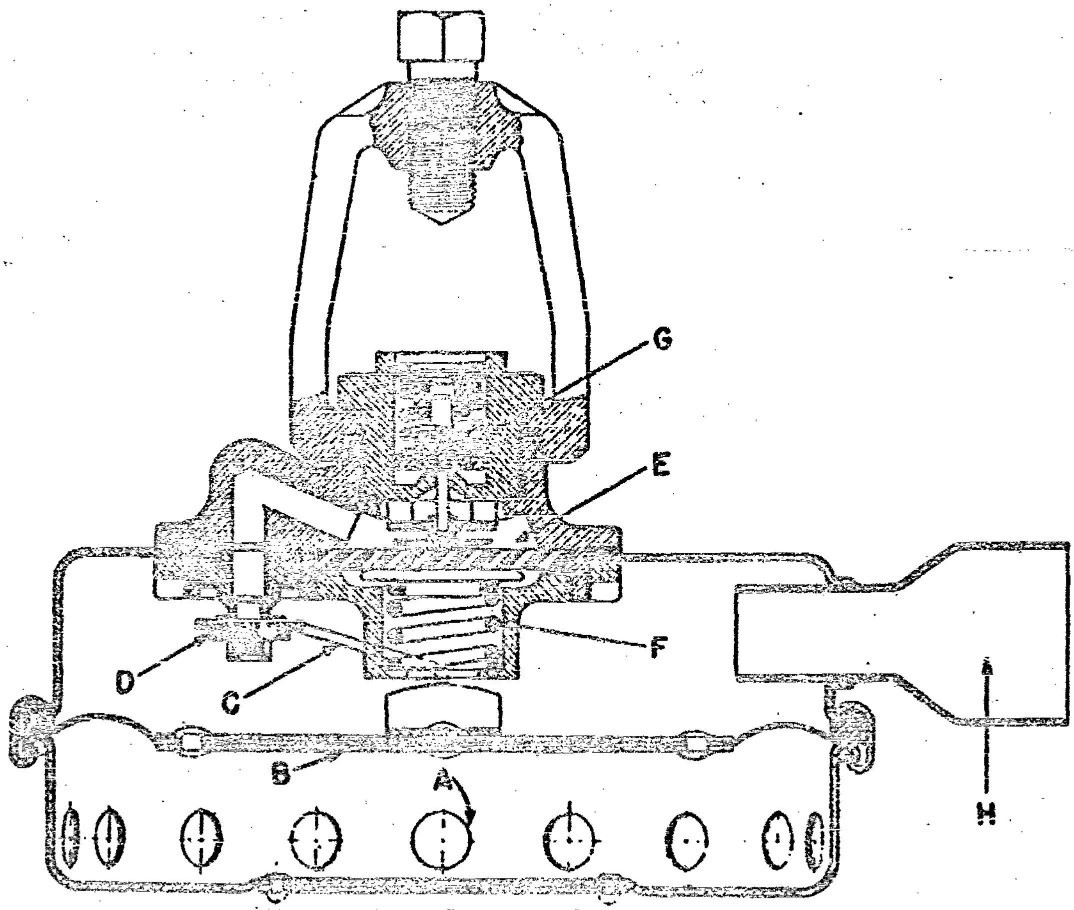
To conserve air the diver must learn to breathe with a slow easy rhythm, taking the air gradually rather than trying to fill the lungs all at once. Nervousness or other disturbed mental attitudes of the diver which induce quick breathing may cut the available diving time by 50%. Using the "flutter kick" described, the diver can learn to obtain perhaps seven kicks from each breath of air when moving any considerable distance under water.

However, the effort the conserve the limited air supply should not be carried to the extent of actual restraint of the desire to breathe (*). Excessive holding of breath can result in shortness of breath and eventual nausea from CO_2 accumulation, especially at greater depths, where it is now bel'eved that CO_2 buildup occurs to some extent even when one is breathing "normally". Increased physical effort naturally increases breathing; and beyond a certain point, respiration becomes uncomfortable and may tend towards uncontrolled gasping. The diver should learn to keep his exertions within this limit--which will generally be reached sooner at greater depths.

Economy of air usage may also be achieved by ascending when an appreciable distance has to be covered between diving locations, and moving through the water just below the surface. The reason for this suggestion follows: Since the demand regulator fills the lungs with air at the pressure corresponding to the depth of operations, the diving time available from a given tank of compressed air becomes less with greater depths. During submersion the lungs fill to the same extent as compared with the surface, but the actual consumption of "free air" (equivalent volume of compressed air at atmospheric pressure) increases nearly in proportion to the number of atmospheric pressures found at the swimming depth.

The average rate of air consumption is in the neighborhood of one cubic foot per minute for a diver at the surface, increasing by 50% or more during exercise. From one series of experiments it was observed (4):

(*) If breath is held beyond the "spasm stage", unconsciousness may quickly follow.



HOW REGULATOR WORKS

Because it unfailingly supplies vital air to the diver, the demand regulator (above) is called the heart of the Aqua-Lung. Water entering the base through holes "A" acts against diaphragm "B", which forms the bottom wall of the lower chamber. Movement of the diaphragm actuates valve "D" through lever arrangement "C", causing air to bleed from the upper chamber "E" into the lower one until the sea pressure is equalized. The pressure in the lower chamber, in combination with the spring "F", then acts to halt the flow of air from the diver's tank through valve "G". When the diver's breathing removes air from the lower chamber through port "H", the cycle repeats itself and is capable of matching the fastest breathing rate. Air exhausted from the diver's lungs is discharged into the water through a valve just below diaphragm "B". Diaphragm and spring-loading devices are so calibrated that the mechanism works on a pressure differential of only 2 to 5 inches of water, and this is readily produced by the lungs.

(*) Reproduced by permission of Compressed Air Magazine, August 1953.

FIG. 2*

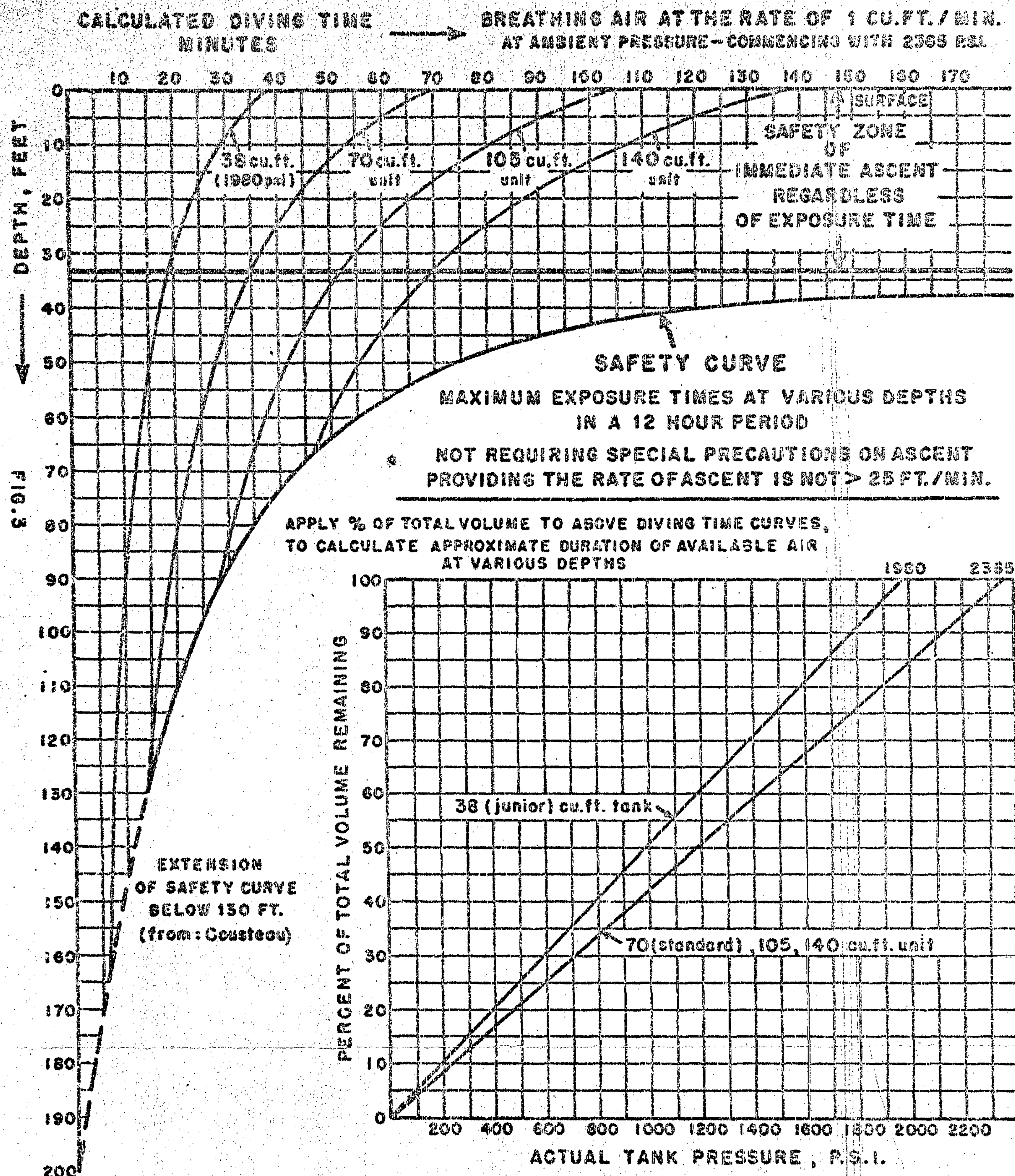


FIG. 3

CALCULATED DURATION OF AIR SUPPLY (*) AT VARIOUS DEPTHS, assuming a constant breathing rate and not allowing for air consumed during descent--and its relation to the "Safety Curve". ((*) Subject to many factors, some described in text).

1. the volume of free air expended at rest increased almost proportionately with the ambient water pressure down to 33 feet, but the volume used at 100 feet was 15% greater than the "calculated" amount. The increased consumption rate at 100 feet may have resulted from shivering in the colder water found at that depth.

2. the volume of free air expended during exercise tended at greater depths to become less than the "calculated" amount. At a depth of 100 feet this amounted to a consumption rate 37% less than predicted.

   This may be partly explained by the increased "partial pressure" of oxygen--equivalent at four atmospheres (99 feet) to breathing 80% oxygen at one atmosphere. This concentration of oxygen is known to reduce the air consumption necessary during exercise at the surface.

However, it must be taken into account that the quoted percentages represented an average of a small number of individual performances, where the effect probably varies from time to time in a given man, as well as between individual swimmers.

The "calculated", or predicted, duration of air supply at various depths shown in Fig. 3 is based on the assumption that the respiratory ventilation of free air increases exactly in proportion to the ambient water pressure expressed in atmospheres. Although, as has been explained, the diver's air consumption cannot be predicted with such accuracy, the graph illustrates the effect of one factor which controls the diving time from a given quantity of air. The "Safety Curve" contained in this relationship was plotted mainly from the U. S. Navy Decompression Table (Fig. 4) and concerns only the problem of "bends".

SECTION II - General Precautions

A. Equipment

Secure the Aqua-Lung to the body with "safety hitches" on the shoulder and waist straps. This is accomplished by passing the end of the strap back through the first buckle for several inches, leaving a loop of perhaps three inches still cinched. One sharp yank on the end of this strap will cause the hitch to come free. This method is not only convenient but allows a quick means of escape from the Aqua-Lung

harness in case of an emergency ditching (see Sect. III-B,D). The weight belt should be attached in the same manner.

An improvement of the standard Aqua-Lung harness, made at the Submarine Escape Training Tank in New London, Conn., consists of four parachute-type wide nylon straps meeting in the form of an "X" on the diver's chest, allowing release of the entire harness from one central point.

If the Aqua-Lung cylinder is equipped with an air safety reserve feature be sure the lever is in the "up" position before commencing the dive. This will insure an advance warning of approaching tank exhaustion (see Sect. III-B). When charging these tanks from a compressor or cascade system of larger cylinders the lever must be in the "down" position.

There are at least three schools of thought concerning the placement of ballast weights carried by the diver:

1. One U. S. Navy group prefers to attach the weights directly to the cylinder(s). Thus, if "ditching" is necessary, all the dead weight of the apparatus falls away in one operation.

2. Most civilian underwater swimmers appear to wear the weights on a waist belt. Therefore, if the Aqua-Lung is taken off at the surface it would not necessarily sink--as it would were the weights attached.

   In the final analysis, however, it is much more important to save your life than the price of an Aqua-Lung.

3. The author has decided to attach the weights to his person. A diver may some day find himself in a situation where he must gain positive buoyancy without parting with his air supply.

Above all, it is wise to keep the number of straps and accessories around the waist down to essentials. This will prevent fumbling when the diver has only a matter of seconds to disengage the equipment. Fastenings should be large and simple enough to be operated easily under water with cold hands or gloves. Many operations which seem quite simple in the air become surprisingly awkward under water.

White parachute cord, leading from the diver to a yellow float, or man at the surface, is a useful precaution providing it is not likely to foul with a ship's screw or dock piling, etc. Always attach the line to the diver's person (not to the Lung or the weights) by means of a large snaphook--which can be easily detached.

If a gasoline-driven air compressor is used to charge the cylinders, make sure that the exhaust gases do not contaminate the air supply through the compressor intake. Very small amounts of excess CO or CO_2 can make trouble for the diver. An excellent example of this trouble is described in Cousteau's book, The Silent World. The air supply should also be filtered free of oil fumes, dust, and moisture.

Never dive with oxygen in the Aqua-Lung, as this can lead to oxygen poisoning--involving general convulsions, fits, and unconsciousness--or an explosion resulting from the presence of oil in the diving apparatus.

A CO_2 inflatable life preserver (*) is highly recommended. There are situations where the importance of this preserver, slightly larger than a cigarette package, could be likened to that of a parachute--in its ability to bring the swimmer to the surface and keep him there.

Always carry a knife, particularly when using or working near lines. Lines are cut best under water with a saw-tooth edge, while a straightedge works on fine wire.

B. Prevention of Air Embolism

A given quantity of air doubles in volume while ascending between 99 and 33 feet below the surface. It will double again in volume during the last 33 feet--a fourfold increase in volume from 99 feet.

Always breathe continuously (or at least exhale) during the ascent, and reduce ascent speed near the surface. A safe rule to follow is: never overtake the small bubbles on ascent. The air in the chest will expand if the breath is held on ascent, and if this is carried to extremes the lung tissues will rupture--forcing air into the blood stream. This results in air embolism (see also Sect. V) and possible death, even though a recompression chamber--the best treatment--is immediately available.

This precaution is especially important in relatively shallow depths since the volume of retained air in the lungs expands at a faster rate as the surface is neared. In fact, an air embolism can result by ascending the last 7 feet while forcibly retaining a full breath. Under extreme conditions

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(*) The FLOTO preserver (Lucas Mfg. Co., Chicago, Ill.) appears to be most suitable, since it can be securely attached to the diver.

of panic, the escape of air could be prevented by a spasm of the throat muscles sealing the main lung passageway.

However, ordinarily the diver would not accidentally reach this point; if not breathing normally the feeling of expansion in the chest, or sensation of discomfort behind the breastbone, would remind him to equalize. The incidence of air embolism is very low, particularly among well-trained and experienced underwater swimmers.

The ascending swimmer should never wait for a feeling of distinct pain in the chest to signal the need for expelling air. The "bursting point" is not predictable. It has been observed at the Submarine Escape Training Tank in New London, Conn., that the few students stricken with air embolism during Momsen Lung escape training or "free escape" (with no breathing appliance) training gave no outward indication of pain in the chest before the onset of symptoms. The danger of air embolism is paramount during the emergency procedure of "free ascent", which is discussed in detail in Sect. III-D.

Incidentally, a skin diver who swims down from the surface without a breathing appliance, holding his breath, is not concerned with this problem since the air pressure in his lungs during ascent never exceeds the starting atmospheric pressure.

While on the subject of air expansion, it might be of interest to note that during very fast compression or decompression (usually occurring only in recompression chambers), one may have pain in defective teeth fillings. During compression (or descent) the air may not get in quick enough to cavities under the filling, so the tooth may cave in. During decompression (or ascent) the air may not escape fast enough and the filling may be lifted out of the cavity. Occurrence of pain in the teeth during diving should prompt a visit to the dentist, since this does not happen when the teeth are in good repair.

During a rapid ascent with the Aqua-Lung the air expanding inside the mask will often cause the mask to shift position. It might be convenient in this case to hold the mask lightly against the face with one hand, or allow the excess air to escape under the lower edge.

C. Avoiding the "Bends" (Decompression Sickness, Caisson Disease)

Below a depth of 33 feet the diver has time limits, diminishing with increasingly greater depths, which allow a normal return to the surface with little (if any) danger

of contracting "bends", although the rate of ascent near the stated limits should not be greater than 25 feet per minute. Consult Section V-D for important facts related to this statement. The U. S. Navy Decompression Table (Fig. 4) lists the exposure time limits (*), i.e., 2 hours at 40 feet, 43 minutes at 70 feet, 25 minutes at a depth of 100 feet, etc.; these are plotted graphically as a "Safety Curve" in Fig. 3. The Aqua-Lunger should use depth-time combinations above this Curve to avoid the need for decompression stops during ascent (**). The deeper portions of the Safety Curve are of little more than academic interest because the descent would use up most or all of the time.

The Aqua-Lunger should remember that (1) the exposure times are cumulative in any 12-hour period, (2) the exposure time limits include both "time on the bottom" and time of descent from surface; exposure times at depths of 33 feet or less are, of course, also counted as decent time, (3) interpolation of the Decompression Table is not permitted. To clarify, this means that if the actual depth or time involved happens to fall between values given in the table, the diver must decompress for the next greater increment of depth or time.

Where the depth measurement is felt to be inexact, or if rough water effectively varies the depth, or if the diver is doing exceptionally hard work, U. S. Navy diving officers will apply the next 10-foot increment of the table beyond that which would normally be used.

The oceanographic Aqua-Lung diver, in particular, may introduce a complication at this point by following an uneven bottom. If the bottom slope is known to be fairly constant, and the depths considerable, the safest rule to follow in this instance: begin the survey at the deep end of the slope and surface when the maximum allowable exposure time for that deepest depth, or the greatest depth encountered (such as a "dip" in the bottom) has been reached. An accurate wrist depth gauge, pressureproofed watch, and compass are necessary items in most diving, particularly in deep water.

(*) Not to be confused with "Optimum Exposure Time" referred to in the Decompression Table.

(**) Consider qualified comment by LCdr. F. D. Fane, COMUDU-1: "Dives of over 170 feet are for experts with recompression chambers immediately available. You are asking for trouble to try greater depths--unless emergency requires."

Depth up to-	Time from leaving surface to beginning of ascent or to up stage for surface decompression	Stop at different depths in minutes				
Feet	Minutes	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.
40	120					0
40	180					2
40	☆ 240					4
40	300					6
50	78					0
50	120					2
50	150					5
50	☆ 190					9
50	300					12
60	55					0
60	75					2
60	110					13
60	☆ 150				3	15
60	180				7	16
60	210				8	18
70	43					0
70	60					4
70	75					13
70	90				4	16
70	☆ 120				13	16
70	150				18	21
70	180				21	32
80	35					0
80	50					6
80	70				6	16
80	100				20	16
80	☆ 115				22	26
80	150				28	29
90	30					0
90	45					6
90	60				9	16
90	75				18	14
90	☆ 95			2	27	21
90	130			9	27	29

Depth up to-	Time from leaving surface to beginning of ascent or to up stage for surface decompression	Stop at different depths in minutes					
Feet	Minutes	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.
100	25						0
100	40						12
100	60					16	16
100	75					27	21
100	☆ 85				6	28	21
100	90				8	27	24
100	120				17	28	48
110	20						0
110	35						12
110	55					22	21
110	☆ 75				14	27	37
110	105			2	22	29	50
120	18						0
120	30						11
120	45					18	21
120	☆ 65				13	28	52
120	100			5	22	27	69
130	15						0
130	35					11	15
130	52				6	20	28
130	☆ 60				13	28	23
130	90			9	22	28	69
140	15						4
140	30					8	21
140	45				5	27	27
140	☆ 55				15	28	32
140	85			14	22	32	69
150	15						7
150	30					13	21
150	38					28	30
150	☆ 50				16	28	32
150	80			18	23	32	68

Depth up to-	Time from leaving surface to beginning of ascent or to up stage for surface decompression	Stop at different depths in minutes								
Feet	Minutes	90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.
160	15									9
160	34								27	28
160	☆ 45							17	28	43
160	75					3	19	23	34	68
170	15									11
170	30								24	27
170	☆ 40							19	28	46
170	75					9	19	23	38	63
185	15									25
185	26								24	37
185	☆ 35							19	28	46
185	65				18	18	23	37	65	51
200	15									32
200	23								23	37
200	☆ 35							22	28	46
200	60			5	18	18	23	37	65	51
210	15									35
210	☆ 30						5	16	28	40
210	55			6	18	18	23	37	65	51
225	15								6	35
225	☆ 27						22	26	35	48
225	60			13	18	18	23	47	65	83
250	15								17	37
250	☆ 25					2	23	26	35	51
250	50		12	14	17	19	29	49	65	83
300	12								20	37
300	20					9	23	26	35	51
300	45	6	14	15	17	18	31	49	65	33

Note: ☆ Optimum exposure time.

Note: Rate of ascent not to exceed 25 feet per minute.

PRNC-CDU-5x

DECOMPRESSION TABLE **U.S.NAVY DIVING MANUAL - 1943.**

FIG. 4

Concerning repetitive dives the author quotes Lt. Edward H. Lanphier, who is attached to the Navy Experimental Diving Unit: "The present Navy rule for repetitive dives leaves much to be desired from the Aqua-Lunger's viewpoint. In the first place, divers are urged not to make more than one dive in a 24-hour period where this can possibly be avoided. If such dives must be made, the rule calls for decompression on the basis of the combined time of the dives and the depth of the last dive. This will seem unnecessarily restrictive and burdensome and this is frequently the case. However, it is probable that in certain circumstances where a deep dive is followed by a shallower one after a short interval, the decompression specified for the last dive would not be sufficient. The only rule which can thus be considered safe in all circumstances is: <u>decompress for the combined times and depth of the deepest dive.</u>"

The French have developed special underwater swimmer decompression tables, characterized mainly by "factors" for repetitive dives on the same day, but the validity of these has not been checked in this country (*).

D. <u>Possibility of Nitrogen Narcosis</u>, or "Rapture of the Depths"

Approach with caution the effects of nitrogen narcosis (see also Sect. V-D), causing progressively greater impairment of judgment and sense of self-preservation, when diving in excess of 80 to 100 feet. The effect at the first 100 feet of depth has been very roughly compared to the equivalent of one strong alcoholic cocktail. Thereafter, each 33 feet of depth (one atmosphere) might be considered as another cocktail. At 300 feet the most experienced diver may falter at the simplest task. Since the individual reaction to alcohol varies widely, the equivalents are used only as a means of descriptive illustration. They refer to "effective" alcoholic cocktails.

"It is the experience of submarine medical officers that men with low alcohol tolerance or emotional instability are especially susceptible to drunkenness caused by high pressure nitrogen. Mature, serious-minded individuals try to overcome the effects of nitrogen under high pressure by determination and will, and can perform useful work at greater depths." (<u>2</u>)

The French Aqua-Lung diver Maurice Fargues, of Captain Cousteau's group, evidently passed out and drowned while under the influence of nitrogen narcosis at a depth of 396 feet, while on an experimental dive (<u>16</u>). Because of this

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(*) Reference to: <u>La Plongee en Scaphandre</u>

experience, Cousteau set the ultimate depth limit for his group of self-contained divers using air at 300 feet (or 250 feet on a "working dive"), which corresponds to the limits generally imposed on conventional deep-sea diving rigs.

However, considering the fact that the self-contained diver is "on his own" and that he has the additional problems of limited air supply and decompression stages to avoid the "bends", the Aqua-Lunger who descends even to 250 feet has one foot on a tightrope between mortality and oblivion.

In conventional suit diving narcosis can be reduced or eliminated by substitution of helium (*) for nitrogen. Unfortunately, for deep dives of limited duration which characterize the Aqua-Lung, this mixture of gases increases the decompression time required to avoid the "bends".

E. On Diving With a Partner

The following is a practice recommended by the National Research Council Panel on Underwater Swimmers (3): "An underwater swimmer should never go alone, but always be accompanied by a partner.

"Daytime -- stay within visual range of each other. In shallow clear water the partner may be a surfaced swimmer, or be in a boat(**).

[of course the partner must have the equipment and/or ability to effect a rescue]

"Night (or reduced visibility) -- use a buddy line 6' to 10' long, connected to a partner.

When a swimmer loses visual contact with his swim partner, he should first listen for his breathing noise, then signal by banging on cylinders. If not located--surface" [and look for bubbles of partner].

Aqua-Lung cylinders painted yellow will greatly extend the visual range and this should be standard practice among

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(*) Use of helium in deep-sea diving involves a very formidable amount of gear and a complex procedure.

(**) A small boat should be tending at any rate, when diving any appreciable distance from shore or large vessel.

civilian underwater swimmers--where obscurity is not required.

The author also suggests that, especially where a considerable distance must be covered under water--as in a geological survey, which may involve various changes of course and many stops--the safer practice would probably limit the number of divers to one pair, to minimize the identification problem.

If two Aqua-Lung divers are swimming together and one should "black out" or lose control after losing the mouthpiece or a coughing spell, etc., the other swimmer must either give the stricken one a sharp punch in the stomach or a tight aqueeze about the chest, to expel at least some of the air before dragging to the surface. This is not an immediate way to make friends, but the measure may save the man's life. The reasons behind this suggestion are readily seen in Section II-B (prevention of air embolism) and Section III-D (the free ascent technique).

If propeller noises are heard at time of ascent, proceed slowly and keep eyes open to avoid being struck.

SECTION III - Corrective or Emergency Procedures Following:

A. Flooded Equipment

If water has crept into the face mask the diver may resort to a standard procedure. Take a deep breath, raise the head, and blow through the nose. At the same time lightly hold the top edge of the mask against the face with one hand. The excess pressure will prevent additional water from entering--as the lower edge of the mask is lifted--while the water already present will be forced out. A method of training consists of diving with full equipment (also including extra ballast to hold oneself down), removing the mask under water, replacing, and expelling the water as described.

As a precaution should the mask flood or come off, the diver should accustom himself to the sensation of diving without a face mask--become used to the resulting reduced vision and to having the nose uncovered in water. The latter may require some practice--water tending to enter the nose while breathing through the mouthpiece--particularly during a descent.

Water which has entered around the mouthgrip into the breathing hoses may be easily removed. The simplest and most convenient method, if very little water is present, is

to swallow the water. Another way consists of taking a deep breath, squeezing the intake hose (on the right)*, and then blowing out most of the water through the exhaust. This performance may have to be repeated several times. Rolling over on the left side will greatly assist by draining water into the exhaust hose. Breathing a little spray is not uncommon and is only a reminder to clamp the mouthgrip a little tighter between the teeth. In fact, the diver's mouth may become parched after breathing the filtered, dry air for an extended period, and he may deliberately allow a slight leak.

However, the presence of water could also mean that the exhaust valve or breathing hoses have started to split from deterioration or other causes. If the mouthgrip is secure and the water cannot be cleared by blowing and swallowing, ascend to the surface and examine the exhaust valve and hoses for leaks. The low-pressure diaphragm (Fig. 2) should also be inspected periodically for signs of flaws.

Accidentally losing the mouthpiece is a little more serious than above, but still well within the experienced diver's ability to overcome. The following method of clearing the tubes is most convenient. With the mouthpiece still removed, roll over on the back. This will place the mouthpiece and, therefore, the lower chamber (shown in Fig. 2) at a relatively low pressure. External water pressure actuates the diaphragm (exactly as in normal breathing) and the automatic rush of air will partially clear the intake tube of water. The diver then inserts the mouthpiece, with bubbles issuing, and clears the exhaust tube as previously described.

In fact the air will come forth at such a rate that the diver may find excess air escaping around the mouthpiece. While clearing the tubes, the inexpert diver may have to swallow perhaps half a mouthful of water in the process. It is also soon found with experience that if the diver breathes face down, and quite slowly, the water present will collect in the front of his mouth instead of spraying down the throat or windpipe.

There is an alternative method of clearing the tubes where the diver is unable to roll over on his back (if entangled). Hold mouthpiece above the head, higher than regulator, until air bubbles through intake tube and point

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(*) Although squeezing the inspiratory tube is not absolutely necessary, especially if the diver rolls over to the left side, this technique may be preferable considering the possibility of a leak in the inspiratory tube side.

mouthpiece opening downward to minimize flooding. Raise head, insert mouthpiece, and clear exhaust hose as described.

The diver must train himself, under the immediate supervision of an experienced diver, to meet these situations of flooded equipment. The best preparation consists of diving to about 8 or 10 feet of water, standing or lying on the bottom with a little extra weight, and removing both ~~mask~~ and mouthpiece simultaneously to practice expelling the water.

B. Exhaustion of Air Supply

Exhaustion of the air supply during a dive is usually not cause for alarm, particularly when the Aqua-Lung cylinder valve features a properly functioning safety reserve device. When the original cylinder pressure falls to approximately 300 p.s.i. the regulator begins to offer increasing resistance to the diver's demand for air. At this point, the diver will also notice the face mask moving in and out with respiration.

Following the onset of these symptoms, the resistance becomes greater until after a minute or two--depending greatly on depth and exertion--the air is effectively exhausted. However, stretching the remaining effective air supply is an exceedingly dangerous practice. When the symptoms are first noticed the diver should immediately turn the reserve lever "down" and make a normal ascent shortly thereafter. Actuating the reserve lever thus releases the "sealed off" 300 p.s.i.--allowing the diver about five or ten minutes, depending on depth and size of cylinder.

If the cylinder does not feature the reserve device, the diver should immediately stop whatever he is doing and ascend to the surface. Providing the diver breathes lightly, the remaining air will probably suffice since the effective volume of air available to the diver increases at a more rapid rate as the surface is neared.

Running out of air is a common occurrence, sometimes fully intentional on the diver's part, and he soon learns with experience the signs of approaching air exhaustion and the appropriate steps to take.

Air exhaustion becomes more serious, however, with increasingly greater depths. Due to the greater consumption of cylinder air at these depths, the initial feeling of restriction will tend to arrive more suddenly and the diver will have less time to "dawdle". Aqua-Lung cylinders not equipped

with the safety reserve device should not be used deeper than 50 feet in general practice.

It should be kept in mind that the diver is likely to become completely absorbed in whatever he is doing, particularly when affected by nitrogen narcosis, and may not realize until quite late that the air supply is approaching exhaustion.

In addition, the remaining air supply may be insufficient to allow a rate of ascent no greater than 25 feet per minute, in order to avoid "bends" near the time-depth limits imposed in the Navy Decompression Table.

There is one characteristic of the reserve lever which the author would emphasize. If the descent was made with the reserve lever accidentally in the "down" position, thus by-passing the reserve indication (or first warning), the diver should consider the situation before belatedly attempting to correct matters under water by turning the lever "up". If enough time has elapsed before the mistake was realized, the tank pressure may have fallen below the approximately 300 p.s.i. stage where the reserve feature normally gives the first warning to the diver. When this has occurred, the air flow will cease <u>abruptly</u> (*) as the lever moves up.

This is important while submerged because the diver may have difficulty, after realizing his second mistake, in returning the lever "down"--due to the hands being cold or clumsy with gloves, or due to a stiff lever.

It is inadvisable to surface with empty tanks too far from shore or assistance, particularly in rough water. Jettisoning the weights (if any) may enable the swimmer to utilize the slight positive buoyancy of the empty tank for floating on his back, but it is not feasible to swim for any appreciable distance with empty tanks on the back. It is impossible to swim face down with empty tanks unless a "snorkel" is at hand. The Fenjohn Underwater Photo & Equipment Co. distributes a combination snorkel-mouthpiece for the Aqua-Lung which could be useful here, although its primary purpose is the conservation of cylinder air--if much swimming is done at the surface.

In the same situation, the inflatable life preserver previously mentioned could save considerable embarrassment--perhaps the swimmer's life. The diver should also accustom himself to releasing the Aqua-Lung harness at the surface and towing the apparatus behind--a technique stressed at the Scripps Institution of Oceanography.

(*) This situation is <u>not</u> similar to normal exhaustion of air supply.

C. Entanglement With Underwater Obstacles

A self-contained diver, in prowling the sea, lake, or harbor bottom--particularly where the visibility is poor or nonexistent--always exposes himself to the danger of becoming entangled with an obstruction or natural marine growth. Dock pilings, mooring and lobster pot lines, fish traps, eel grass, and kelp (a seaweed with long stems) are typical hazards. When this unforeseeable event occurs the diver should remain calm and think his way out of the situation--a rule which actually applies to every underwater emergency. Thrashing about only may entangle him further and waste valuable air.

Two strong aids in this sort of disaster are (1) a substantial knife, (2) an accompanying diver. In the event that the diver cannot free himself from the entanglement (assuming here that only the apparatus is caught), he must attempt to "ditch" the apparatus and make a "free ascent" to the surface. The diver should not part with his air supply unless all else fails; neither should he wait until the air supply is exhausted before disengaging the harness.

D. Free Ascent Technique

The free ascent technique for Woods Hole Oceanographic Institution divers should be learned under the supervision of naval personnel at the Submarine Escape Training Tank in New London, Connecticut. The student diver ultimately learns to reach the surface safely--through as much as 100 feet of water--after discarding his Aqua-Lung on the bottom.

The term "free ascent" may also apply to a situation where the ascending swimmer makes no use of his breathing appliance, though still attached to his person.

Success of the free ascent technique depends upon the ability of the swimmer to remain reasonably calm and collected. Before attempting the Aqua-Lung "ditch" and free ascent at the Escape Tank, the student diver must feel thoroughly at home in his apparatus.

Assuming that the air supply is sufficient for the ditching operation, the diver releases the weight belt (if any), proceeds to unfasten the two or three buckles which secure the Aqua-Lung. If the safety hitch was applied before the dive, one quick yank on first the waist and then the shoulder straps will cause the apparatus to fall free. Before starting the ascent, the diver clears his lungs with several deep breaths, drops the grip from his teeth, and if necessary throws the grip over his head.

At this point the swimmer presumably will be buoyant (*) and begins to float slowly upwards. To conserve oxygen he should refrain from all bodily movements--even that of shoving off from the bottom. The correct posture, as taught at the New London Escape Tank, is an erect, "streamlined" position, with the hands at the sides (**) and head tilted up to watch the bubbles. After rising perhaps 4 or 5 feet (***) he should begin releasing a small, steady stream of bubbles--as if through a soda straw. The most important part of the free ascent technique is to ascend no faster than the bubbles emitted. As long as the swimmer ascends at a fairly steady rate, while at the same time surrounded by his bubbles, he will make a successful free ascent from at least 100 feet [time: approximately 45 to 60 seconds].

Trained personnel have made free ascents from depths of 200 feet in the open water. There are also a few cases on record where submariners with no previous training in this technique have made successful free ascents from depths of 200 to 250 feet; the latter, however, must be attributed to "fortunate circumstances". (7)

If the diver feels that he is overtaking the bubbles, he blows out air at a slightly faster rate in order to reduce buoyancy and slow down. If, as a consequence, he releases a little too much and slows almost to a standstill, the breath is held for a few seconds until a suitable speed is again reached.

On the other hand, the swimmer may have grossly overcorrected in his attempt to reduce ascent speed, expelled too much air, lost positive buoyancy, and started sinking. Then, he must not panic (this is a critical point) but hold his breath for a few seconds while propelling himself up until positive buoyancy is regained.

(*) "If a man has positive buoyancy at the surface, then when he fills his lungs to the same extent at any given depth, he will also have positive buoyancy regardless of the depth." (Excerpt from: Manual of Free Escape from Submarines).

(**) In the open water, where visibility may be poor, an arm should be extended above the head to fend off possible obstructions.

(***) During Escape Tank training, the ascending diver observes that at greater depths a relatively long pause before releasing air will be necessary, and fewer bubbles released thereafter, in order to maintain positive buoyancy. As the surface is neared, however, the more rapidly expanding air should be relieved by larger bubbles.

The Escape Training Tank at the New London Submarine Base. Instructor (giving hand signal) and pupil are making a "free ascent", after breathing compressed air in a lock.

FIG. 5

The swimmer may have to rely on his physical sensations to ascertain whether he is rising or falling, and at what rate. If the light is dim and the friction of the passing water is not noticeable, the sure sign of an ascent occurs when the air inside the face mask expands and tries to leak around the edges. Conversely, if descending the mask will press more tightly against the face. Human senses may become very confused in a watery environment, particularly when excited and the water is murky, with no fixed reference point. Particles suspended in the water may prove to be very useful reference points. Hairy-chested divers of considerable experience claim that the chest hairs may give an indication of direction.

The point must be stressed here that if the ascent is properly executed, at no time will the diver feel short of breath. As he floats upwards to the surface the air expands in his lungs and his only concern is to get rid of the excess gas. Aside from a possible lack of coordination, the untrained free ascenter has the most to fear from fear itself--which will burn up precious oxygen.

If the foregoing procedures are disregarded, the swimmer will either consume the oxygen stored in his lungs through strenuous swimming movements or if the surface is reached, an air embolism may result. The importance increases with the starting depth; a free ascent from 15 feet will tolerate more errors in technique than an ascent from 115 feet. The coordination may be difficult to attain without previous training under controlled conditions.

The swimmer inherently negatively buoyant (perhaps 3% of individuals) will presumably have to use his swim fins during the entire ascent, and a safe arrival at the surface may not result unless there is a line to follow.

When making a free ascent after squeezing (to inflate) a CO_2 preserver, keep the volume of air in the lungs near the minimum to avoid the distension which could result from the rapid ascent.

E. Eardrum Perforation

A diver with perforated eardrums may discover his sense of balance and direction temporarily upset. In fact he may not distinguish "up" from "down", and proceed in the wrong direction.

"If an eardrum should perforate while submerged, the cold water may temporarily cause a temperature imbalance in the vestibular apparatus--resulting in a real hazard in that

nausea and dizziness can occur. The swimmer is safe if he keeps his mouthpiece in place and remains calm for a few minutes until the cold water entering the ear becomes warm and the violent vertigo is ended. Holding onto a submerged object, or even hugging oneself might assist." (3)

SECTION IV - Suggested Safety Precautions and Requirements (Physical and Psychological) for Underwater Swimmers

A. <u>From the U. S. Navy and National Research Council Panel on Underwater Swimmers</u>

Since swimming involves a physical exertion comparable to running, a diving candidate should be in a state of general good health. Past history or evidence on complete physical examination of chronic respiratory or cardiovascular disorders should bar a man from this activity. Other eliminating maladies are: middle ear disease, exaggerated susceptibility to motion sickness, unusual sensitivity to cold water exposure, excessive fear of the dark, claustrophobia, or a tendency to take unconsidered risks.

The swimmer must be psychologically and physically fit:

1. Must pass periodic (perhaps semiannual) check ups, with particular emphasis on the heart and respiratory systems.

2. Must "feel O.K."--i.e., must not dive nor be penalized for not diving when seriously desiring not to.

(*)3. Must not dive after excessive drinking of alcohol until well rested and ill effects have passed.

(*)4. Should be well rested (usually eight hours of sleep the night before dive) and when possible should be permitted to rest after the dive. [In addition to resting after a long, deep dive the breathing of pure oxygen at the surface for about ten minutes will help clear the blood of any excess nitrogen].

5. Should not dive immediately after eating; vomiting may cause asphyxiation.

(*) Excessive alcohol in the system, or fatigue, can cause a diver to become more susceptible to the "bends".

6. It is highly desirable that the diver be "in shape". Regular exercises of running and skin diving have been found to be good conditioners for underwater swimmers.

7. Must like to dive. Underwater swimming should definitely be a volunteer activity.

8. The underwater swimmer must be well aware of his own psychological and physiological limitations.

B. <u>Outline of Recommended Training for Woods Hole Oceanographic Institution Diving Candidates</u>

1. Complete physical examinations, at least annually, by a civilian physician and an ear-nose-throat specialist (preferably one who is familiar with complications resulting from pressure inequalities).

2. Diving instruction at Woods Hole Oceanographic Institution--an undetermined length of time, but probably at least six weeks. Particular emphasis would be placed on the diver's ability to cope with pressure changes and flooded equipment.

The above preparation may be sufficient for those individuals who will restrict their diving to depths of about 40 feet or less.

The advanced training listed below should be necessary (if available) for serious, long-term workers who plan diving to depths greater than about 40 feet.

3. Advanced training in underwater techniques (total--one week) at Escape Training Tank, U. S. N. Submarine School, New London, Conn., which may include:

    (a) Diving physical examination by submarine medical officer (in order to qualify for the following):

    (b) Dry pressure test in the recompression chamber to 50 p.s.i., equivalent to 112 feet of sea water.

    (c) Momsen-Lung ascents from the 18, 50, and 100 foot escape locks.

(*) (d) Free ascents from the 18, 50, and 100 foot escape locks.

(*) (e) Aqua-Lung jettison and free ascent to the surface from the 50 and 100 foot levels.

(*) (f) Formal lecture on underwater physiology, by submarine medical officer.

4. At least two weeks' training in the open water using the Aqua-Lung with Navy swimmers. OPTIONAL--though very useful in broadening experience.

SECTION V - Further Discussion of Some Physiological Consequences of Diving

Introduction

This section will provide the reader with a background of information concerning physiological aspects of diving which previously in this report were only touched upon. However, this section is no less important to the underwater swimmer's welfare.

The author gratefully acknowledges the assistance of U. S. Navy medical officers in the preparation of this section, which is in part quoted verbatim from them.

A. Ear Care and Complications Due to Pressure Inequalities

1. "Ear fungus" is almost an occupational disease of men who dive frequently without suits, particularly in contaminated water or in warm climates. The actual infection, however, is almost always due to bacteria similar to those which cause pimples and boils. Whether due to bacteria or fungus, prevention lies mainly in keeping the ear canal as dry as possible after each dive. Rinsing the ears with a few drops of 50 to 70% alcohol will accomplish drying without fuss, strain, or significant irritation (which may result from using swabs).

(*) At the present time, this training may be obtained only by special temporary assignment to a Navy U.D.T. group, with consequently fewer opportunities for the free ascent training. If this is accomplished, however, the U.D.T. training will also include that covered in (a), (b), and (c).

Since an excess accumulation of ear wax will make drying the ears more difficult and favors the accumulation of dirt, it should be syringed out occasionally by a physician.

2. Continued descent in spite of inability to equalize pressure will produce at least some engorgement of the small blood vessels in the eardrum and the lining of the middle ear. Repeated insults may very well result in some degree of hearing loss.

When hemorrhage results from rupture of these vessels, following additional descent, pain will be experienced (if not already present) which may continue for some hours. Beyond this stage actual rupture of the drum will take place. In some individuals rupture can occur without significant warning pain.

Once ruptured, the drums generally heal uneventfully in a few weeks; but the fact that deafness occasionally results means that the accident is not to be taken lightly. The principal danger following rupture is that of middle-ear infection. Following examination by a physician, the usual rule for treatment is a strict "hands off" policy--including the insertion of fingers, swabs, plugs, medications, and especially water. Further diving of any type must be avoided until permitted by the examining physician.

3. When wearing a hooded suit the diver may experience a sensation similar to that of failure to equalize through the eustachian tubes, even though the diver is clearing his ears easily. In this case the diver has another closed-off space between the drum and the hood (since the hood is in itself a closed, nonequalizing structure). This condition can be rectified if a little air can be blown past the mask seal into the hood. The consequences of failure to equalize this pressure are similar to those seen in the more common middle-ear condition.

There is another phenomenon which may perplex the observer who is unfamiliar with this mechanism. The diver may return to the surface with blood dripping out of his ear, though he insists that he "cleared" easily all the way down, and may not have a rupture. In these cases the relative negative pressure has "pulled" a blood blister on the drum, which then ruptured to the outside leaving the drum as a whole intact.

Pressure in the face mask must also be equalized on descent. This is easily accomplished by letting enough air out through the nose to relieve the sensation of suction on the face. Failure to do this will produce a

localized "squeeze" and may thus result in nosebleed, hemorrhages of the conjunctive, wrinkling of the skin with inward leakage of water, etc. Goggles should not be used unless provided with some means of equalizing pressure (i.e., a small tube leading to the mouthpiece).

4. Nosebleeds following exposure to pressure changes probably consist of either nasal bleeding from a squeeze of one of the accessory sinuses, usually requiring no treatment beyond abstinence from pressure changes for a day or two; or nasal bleeding from a hemorrhage into the middle ear draining through the eustachian tubes (the latter usually occurring when the diver with hemorrhage surfaces face down, with the blood entering the posterior nares instead of the throat). This condition does not require any more treatment than the first type of nasal bleeding.

The colored nasal discharge following deep dives is the result of the air pressure in the sinus forcing out a mucopurulent or purulent material from a chronic sinus infection. This drainage is of distinct benefit to the individual, though damage will accompany if there are significant obstructions. Considering the latter possibility, the individual with a known sinus condition should not deliberately attempt to force out the material through pressure changes.

An examination of the ear following a middle-ear hemorrhage through the eustachian tubes will reveal a relatively red eardrum or evidences of distinct hemorrhage behind the drum. Usually no treatment beyond abstinence from pressure changes is prescribed by the examining physician in these cases, unless there is evidence of excessive lymphoid tissue around the eustachian tube opening which prevents proper equalization of pressure. The danger of middle-ear infection is not very great following this type of hemorrhage.

The spitting of blood is usually the result of middle-ear hemorrhage draining through the eustachian tubes, but can also occur following a squeeze of one of the accessory sinuses.

5. Slight blockages of the eustachian tubes and nasal sinuses may be cleared by using a Benzedrex inhaler or a nasal spray or drops such as 0.25% neosynephrine, 1.0% ephedrine sulphate, 0.05% privine, etc. These measures, in the case of an anticipated blockage, must be taken before the first dive--instead of as a cure for the next immediate attempt. A person with a bad cold should not dive, as infectious material may be forced into the middle ear.

B. Air Embolism

When the lungs expand to a critical extent (possibility indicated in Sect. II-B), the excess internal pressure ruptures the lung air sacs and blood vessels. Air is forced into these ruptured tissues and blood vessels, causing air bubbles (the "emboli") to enter the pulmonary capillary bed. From there the bubbles are carried to the left chamber of the heart and the arterial blood vessels where they produce the various symptoms of circulatory blockage (the definition of "embolism") in the heart, brain, spinal cord, or other vital organs (2).

The manifestations of air embolism may vary according to the individual, the severity of attack, and the time elapsed since onset. The following are symptoms usually seen or felt in a severe type of air embolism (2, 8)):

1. A "pulling" sensation in the middle of the chest

2. Reddish or other froth at mouth

3. Increasing numbness in the extremities, with arms and legs gradually becoming rigid

4. Balance becoming unsteady; dizziness

5. Convulsions and biting of the tongue

6. Losing consciousness and becoming cyanotic (bluish)

The symptoms below may be seen in less severe types of air embolism, or in subcutaneous emphysema (air in the tissues and not in blood vessels). The latter is often called "air embolism", but not correctly so. It is less serious, but should be treated.

1. A fullness in the throat

2. Voice changing to a brassy, flat quality

3. Speech becoming thick and mushy

4. A "rattling" sound with breathing

5. An inflated condition of the skin over the collarbone

Treatment of air embolism involves recompression--as soon as possible--in a pressure chamber, where the constricting air bubbles are diminished in size. Relief may be

expected if the duration and severity of symptoms are not too great. However, death can result in severe cases by cerebral anoxia or cardiac insufficiency even after prompt treatment in a pressure chamber.

It has been suggested by Kinsey et al. (8) that "placing the casualty in the left lateral position with the head lowered while being transported to the recompression chamber and during treatment" may possibly save lives in some circumstances.

There is no definite proof of the usefulness of this position, but it is felt that the position may have some possibilities on the theoretical level.

C. Decompression Sickness (more commonly known as "bends")

A definite amount of nitrogen is always present in a dissolved state throughout all body tissues, varying among individuals according to their body weight and fat content. The degree of body saturation during a dive is dependent upon three main factors--depth of dive (pressure head), length of dive (exposure time), and circulatory efficiency. The dissolved nitrogen in the blood and tissues is only slowly gained or lost by the body through respiration, and tends to remain in solution except during changes from greater to lesser pressures.

The escape of this gas is called decompression, and the time required for the process is known as decompression time. If the decompression time is inadequate the blood and tissues approach a state of supersaturation; i.e., they contain more dissolved gas than they are capable of holding in solution. If the human body contains dissolved nitrogen at a pressure more than twice the outside pressure, bubbles are formed in the blood stream and tissues faster than the lungs can eliminate the excess gas.

The bubbles bring about a condition of circulatory blockage or local tissue destruction and, depending on the site, produce symptoms of asphyxia and chokes (bubbles trapped in blood vessels of the lungs and heart), pain or paralysis (bubbles trapped in brain, spinal cord, or nerves), stiffness and soreness of joints and muscles, and itch or rash of the skin.

Redescent or recompression in a pressure chamber will force the bubbles back into solution and subsequent slow return to atmospheric pressure will usually provide complete recovery, as the excess nitrogen in solution diffuses from the lungs. The diver afflicted with bends should be treated

at the first manifestation of the sickness. Failure to observe this rule may result in permanent damage should the sickness develop to an advanced degree.

To those people who, following the onset of symptoms, would recompress in the water with a spare Aqua-Lung, it must be stressed that improper treatment can leave the diver in a condition worse than if he had waited for proper treatment. The proper treatment requires that the nitrogen bubbles be completely absorbed in solution as well as squeezed down to nonsymptomatic size; otherwise recurrence of symptoms will follow--aggravated by the fact that the diver may have taken up more nitrogen during recompression. The location of the nearest recompression chamber, and means of fast transportation in case of emergency, should be known to every diving activity.

Those tissues which require the longest time to become completely saturated with nitrogen will govern the rate of ascent. Because fat is capable of holding over five times as much dissolved nitrogen as the water of our blood and tissues, it naturally will require a longer time to desaturate this type of tissue. There are also tissues within our body which are supplied by a meager flow of blood for normal sustenance. These tissues will also require a longer period of time to rid themselves of their nitrogen since the sluggish rate of blood flow through them offers sluggish gas diffusion. Experiments conducted on man show that a period of 9 to 12 hours is required to rid the human body of its excess dissolved nitrogen. (2)

Divers are decompressed according to a schedule (see Fig. 4) which never allows the nitrogen pressure in the tissues to exceed twice the total ambient pressure; within this ratio of 2 to 1, bubbles will not form. For this reason the Aqua-Lung diver may ascend continuously (minimum decompression time) to the surface from a depth of 33 feet (2 atmospheres) regardless of exposure time.

Because of the relatively long time necessary for fatty tissues to become completely saturated with nitrogen, the obese diver will have the advantage over the lean individual in the case of a short, deep, "bounce" dive. Conversely, the lean diver will have the advantage in a long, working dive.

The probability of decompression sickness in any given dive is also known to increase with exercise and age. Recent over-indulgence in alcohol, excessive fatigue, or a general rundown condition should bar a man from diving activity.

"Susceptibility to decompression sickness varies greatly among individuals and to some extent in the same individual from time to time. It is also influenced by diving conditions in ways which are difficult to predict. Consequently, a decompression table which prevented bends in all cases would involve much more restricted depth-time limits and much longer decompression stops than would be necessary or practical for the vast majority of dives.

"The Navy standard decompression table was developed and tested with this fact in mind. It was considered better to encounter, and treat, an occasional case of bends than to use a perfectly safe but impractical table. Diving to the exact depths and times specified may produce an incidence of decompression sickness up to 5% without being considered unacceptable. At some depth-times, the actual incidence may possibly be slightly higher.

"The point for Aqua-Lung divers to remember is this: the standard decompression table does not have the large built-in safety factor which rumor attributes to it. The fact that it has been violated without serious consequences can be attributed to luck and the lack of susceptibility of the individuals concerned--neither or which can be depended upon indefinitely. Even applying the table 'to the letter' can be expected to result in decompression sickness occasionally--and this is a much more serious matter where a recompression chamber is not at hand than it is in the usual Navy situation for which the table was designed. There is no room in Aqua-Lung diving for taking liberties with the table--or even for 'cutting it close'." (quoted from Lt. Edward H. Lanphier, (MC), USNR).

The symptoms of compressed air illness have been found to occur with the following frequency (2):

Local Pain	89 Per cent
Leg - 70% of these cases	
Arm - 30% " " "	
Dizziness	5.3 " "
Paralysis	2.3 " "
Shortness of breath	1.6 " "
Extreme fatigue and pain	1.3 " "
Collapse with unconsciousness	0.5 " "

The typical case may begin with itching or burning of a localized area. There may be a feeling of tingling of the skin, or numbness. Occasionally there will be small red spots which vary from the size of a pin to that of a dime. A review of several sets of statistics gives the following figures (2):

50	per	cent	occurred	within	30 minutes	after	regaining	surface
85	"	"	"	"	1 hour	"	"	"
95	"	"	"	"	3 hours	"	"	"
1	"	"	delayed over		6 hours	"	"	"

D. Nitrogen Narcosis

The main constituents of air and their proportions by volume are roughly: Nitrogen - 79%, Oxygen - 21%, Carbon Dioxide - 0.03%. Like most inert gases, nitrogen in the air breathed at high ambient pressures can decrease mental clarity, impair judgment, and produce poor muscular coordination in a manner similar to that found in alcoholic intoxication. The narcotic effect is related to the "partial pressure" of inhaled nitrogen and is therefore a function of the diving depth. Nitrogen is not in itself harmful (the narcosis disappears on return to more reasonable depths) but the impaired judgment interferes with performance and may precipitate accident.

The narcotic effects increase progressively with depth until at about 280 to 300 feet even routine tasks become extremely difficult. As in the drinking of alcohol, personality, motivation, and training in a specific task account for the different reactions among different men.

Although the process is complex and still an issue among diving physiologists, experiments show that the narcosis may be at least partly due to a retention of CO_2 in body tissues. Nitrogen, a relatively heavy gas, under high pressure tends to obstruct diffusion of CO_2 from the lungs.

The Meyer Overton theory of nitrogen narcosis states that the narcotic action of gases is directly related to the relative solubility of the gas in fatty organs (i.e., brain and spinal cord) and in water (i.e., blood and tissue fluid). For example, nitrogen has a 5.24 to 1 ratio while helium has a 1.7 to 1 ratio, which explains the markedly lessened narcotic action of helium under pressure. It may be that the lipids in the central nervous system act as oils in dissolving the nitrogen, and then act as narcotics under pressure.

In any event, immediate relief from nitrogen narcosis is gained by reducing the ambient "partial pressure" of nitrogen. There is no aftereffect.

E. A Review of the Salient Features of Air Embolism, "Bends", and Nitrogen Narcosis

There is often confusion between the terms "air embolism", "bends", and "nitrogen narcosis". The following summary outlines some conditions common to the afflictions but differentiates them on the basis of origin and physiological effect.

1. The ascending diver may develop an embolism (circulatory blockage), caused by the presence of air or nitrogen bubbles in the blood stream. This disorder occurs only during or following ascent if certain precautions are not observed.

   (a) In the case of air embolism, the blockage occurs as the result of air introduced from ruptured (overexpanded) lung tissues, when a disturbed mental attitude of the ascending diver prevents the normal relief of expanding air in the lungs.

   (b) In the case of "bends", however, an embolism results from the formation of nitrogen bubbles within the blood stream--the gas being previously in solution. The excess nitrogen, from the breathing air under high pressure, had slowly dissolved in the blood stream and locally formed bubbles after a too rapid ascent (or relief of ambient pressure). The diver has no voluntary control over this process other than ascending by decompression stages sufficiently slow to allow the excess nitrogen to leave the body through respiration, if certain time-depth limits imposed by the Navy Decompression Table have been exceeded.

   "Bends" will also refer to the squeeze of tissues and nerve cells if nitrogen bubbles form outside the blood stream. This congestion may occur during a less severe attack of the "bends".

2. Nitrogen narcosis refers to the temporary drugging action of high pressure nitrogen on the central nervous system; the condition exists only as long as the diver breathes air at pressures considerably greater than atmospheric. The symptoms of nitrogen narcosis, unlike those of air embolism and "bends", completely disappear on return to more normal pressures. There is no aftereffect.

BIBLIOGRAPHY

1. Overhauling the Aqua-Lung, by G. F. Hetzel, Scripps Institution of Oceanography, SIO Ref. #53-28, April 1953

2. Diving Manual, NAVSHIPS 250-880, Bureau of Ships, 1 July 1952

3. On Using Self-Contained Underwater Breathing Apparatus, by W. A. Hahn and C. J. Lambertsen. National Academy of Sciences, National Research Council Publication 274, January 1953

4. Report of the Cooperative Underwater Swimmer Project, by Amphibious Forces-Pacific, S.I.O., N.R.C., O.N.R., January 1953

5. Submarine Medicine Practice, BuNavPers, March 1949

6. Theoretical Considerations of the Use of the Air-Filled Submarine Escape Appliance from Great Depths, by H. J. Alvis, Medical Research Laboratory, U. S. N. Submarine Base, New London, Conn.; Report #185, Vol. XI, No. 2, 27 January 1952

7. Manual of Free Escape from Submarines, by H. J. Alvis, Medical Research Laboratory, U. S. N. Submarine Base, New London, Conn.; Report #184, Vol. XI, No. 1, 10 January 1952

8. Four Cases of Air Embolism Occurring as the Result of Submarine Escape Training, by Jack L. Kinsey (Medical Research Laboratory, U. S. N. Submarine Base, New London, Conn.). Armed Forces Medical Bulletin (submitted for publication).

9. Human Physiology Under High Pressure. I. Effects of Nitrogen, Carbon Dioxide, and Cold, by E. M. Case and J. S. Haldane. Jour. of Hygiene, Camb., Vol. 41, No. 3, November 1941

10. Decompression Sickness (Caisson Disease, Divers and Fliers Bends, and Related Syndromes), by J. F. Fulton, N.R.C. W. B. Saunders Co., Phila. & London, 1951

11. The Treatment of Decompression Sickness (an analysis of one hundred and thirteen cases), by Van Der Aue, G. J. Duffner, and A. R. Behnke. Jour. of Indust. Hygiene and Toxicology, Vol. 29, No. 6, November 1947

12. Physics and Physiology of Diving Decompression, by H. Schenck, Jr., Amer. Jour. Physics, Vol. 21, No. 4, pp. 277-280, April 1953

13. Life at High Pressures, by Prof. J. B. S. Haldane, F.R.S. Science News 4, Penguin Books, England, 1947 (article)

14. Deep Diving and Submarine Operations, by R. H. Davis (Siebe, Gorman & Co. Ltd.) The Saint Catherine Press, Ltr., London, 1951

15. Shallow Water Diving, by H. Schenck, Jr., H. Kendall. Cornell Maritime Press, 1950

16. The Silent World, by Capt. J.-Y. Cousteau. Harper & Bros. 1953

17. Fish Men Explore a New World Undersea, by Capt. J.-Y. Cousteau. The National Geographic Magazine, Vol. CII, No. 4, October 1952 (article)

18. La Plongee en Scaphandre, by P. Tailliez, F. Dumas, J.-Y. Cousteau, H. Alinat, and F. Devilla. Editions Elzevir, Paris, 1949

19. Manuel de L'Homme Sans Poids (Plongeur Autonome), by Robert Gruss. Editions Maritimes et Coloniales, Paris, 1953

20. L'Exploration Sous-Marine, by Dimitri Rebikoff. B. Arthaud, Paris, 1952

21. Diving to Adventure, by Hans Hass. Doubleday & Co., 1951

22. Free Diving: A New Exploratory Tool, by W. N. Bascom R. R. Revelle (Scripps Inst. of Oceanography) American Scientist, Vol. 41, No. 4, pp. 624-627, October 1953

23. The Skin Diver, P. O. Box 128, Lynwood, California (periodical)

24. Sharks and Shark Repellants, by Dr. Hugh Bradner (University of California, Berkeley). The Skindiver Magazine, April 1953 (article) pp. 5

25. "Sea Otters" Rescue Shark Victim, by R. B. Shaw. The Skindiver Magazine, February 1953 (article) pp. 14

26. Sharks and Their Behavior (with particular reference to eight Genera implicated in reports of attacks on man), by Stewart Springer - Emergency Rescue Equipment Section, Office of the Coordinator of Research and Development, U.S.N., Washington, D.C., October 20, 1943

27. Fishes of the Western North Atlantic - Chapt. 3, Sharks, by Henry B. Bigelow and W. C. Schroeder. Mem. Sears Found. Mar. Res., No. 1, Part 1, 1948. pp. 59-546

28. That Misunderstood Fish, the Shark, by Philip Wylie. True Magazine, November 1952 (article) pp. 33, 62, 64, 66

29. The Admirable Barracuda, by Philip Wylie. True Magazine, April 1952 (article) pp. 35, 37, 54, 55, 56

The following references outline some reading which the author has found appropriate to the subject of cold-water immersion.

30. Human Immersion and Survival in Cold Water, by C. H. Wyndham and D. K. C. MacDonald. Nature, Vol. 167, April 21, 1951. pp. 649

31. Research and Development of Life Saving Equipment, Medical Aspect of Shipwreck, British Intelligence Objective Subcommittee, Reprint No. 484, September 18, 1945

32. Auricular Fibrillation Following Hypothermia - Report of a Case, by A. Graybiel Capt(MC)USN, and C. J. Dawe Lt(j.g.)(MC)USNR, U. S. Armed Forces Medical Journal, Vol. 1, April 1950

33. The Pathologic Effects of Cold, by C. P. Yaglou and A. R. Behnke. Chapter 94 In: "Principles of Internal Medicine", by T. R. Harrison. The Blakiston Co., Phila. & Toronto, 1950, pp. 759-761

34. Physiological Responses of Men to Chilling in Ice Water and to Slow and Fast Rewarming, by A. R. Behnke and C. P. Yaglou. From the Naval Medical Research Inst., Bethesda, Maryland. Journal of Applied Physiology, Vol. 3, No. 10, April 1951. pp. 591-602

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